(54) Title: A METHOD AND APPARATUS FOR SENSING IMPACT BETWEEN A VEHICLE AND AN OBJECT
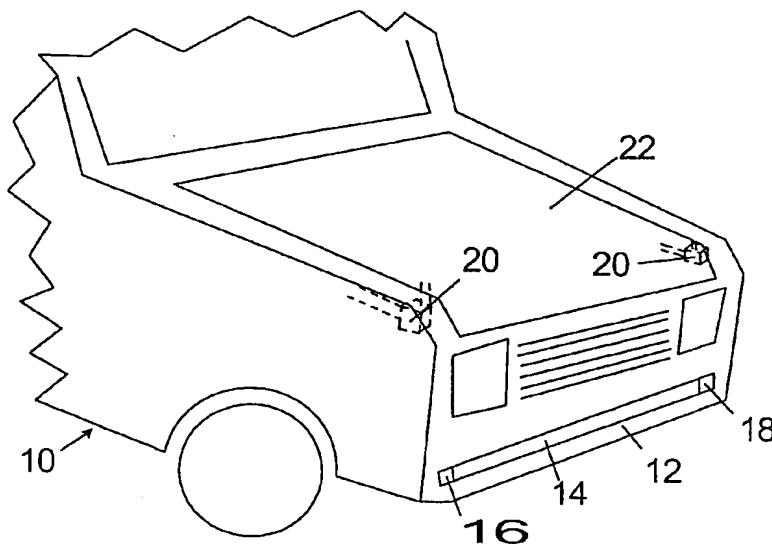
(57) Abstract: The invention relates to the apparatus for and a method of sensing impact between a vehicle and an object and
particularly between a pedestrian and the front bumper(12) of a vehicle. An optical fiber array(14) extends along the bumper (12)
and the array (14)has sensors spaced along the bumper (12). A sensor comprises light loss areas spaced peripherally and axially on a
fiber. An impact distorts the sensors, modulating light transmitted along the fiber or fibers. A signal is produced which is processed
by a signal processor and an output signal generated. The output signal is used to actuate a safety device, such as elevating the vehicle
hood to increase clearance between hood and engine, to reduce the severity of any injuries.

A METHOD AND APPARATUS FOR SENSING IMPACT
BETWEEN A VEHICLE AND AN OBJECT

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Field of the Invention

This invention relates to the sensing of impact between objects and a vehicle, and in particular to classification of the impacts to discern whether a pedestrian has impacted the front bumper of a vehicle. The invention also relates to the use of such
10 sensing to actuate a safety device for the reduction of the severity of injury which may occur due to such impacts.

Background of the Invention

It is an urgent requirement that the severity of injury to a pedestrian resulting
15 from impact with a vehicle be reduced. A particular event such as a pedestrian being in impact with the bumper of a vehicle can result in serious head injuries by the head striking the hood. Although some deformation of the hood can occur, the degree of deformation is restricted by the solid metal of the engine beneath. One possibility that has been proposed is for the hood to be "popped" open to provide some
20 increase in the clearance between hood and engine, allowing increased deformation of the hood. In the case of sensing pedestrian impact, it is also desirable to distinguish whether the impact is due to contact with a pedestrian or something other than a pedestrian, e.g. a pole. Distinguishing between the two is desired in order to deploy the appropriate safety system. In the case of pedestrian impact, in addition
25 or in place of the use of an automobile hood, other safety devices can also be actuated, such as air bags.

Discussion of the Prior Art

It has been proposed to position impact sensing devices on a front bumper, to
30 actuate some form of safety device on the occurrence of an impact. However there is a problem in obtaining clear satisfactory indication of an impact. One such proposal is described in US patent 6329910, in which an elongate metal bar is positioned in the lower air dam area of a bumper, the bar comprising a magnetosensitive sensor and a stress-conducting member. Drawbacks to this

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method include limited flexibility of the components, unlikely return to a working condition after an impact, and interference from electrical fields and impulses. Prior art also includes piezoelectric films such as polyvinylidenedifluoride (PVDF) which produce an electrical current when bent. PVDF sensors suffer from variability of response, poor integrity of electrical connections when bent, and the requirement for high impedance circuitry with consequent reliability problems in wet environments. It is also possible to sense impacts with conductive rubber sensors, which change impedance when stressed or bent. Drawbacks include poor flexibility at low temperatures, material properties which must be tailored for both mechanical flexibility and electrical conduction, and changes in sensitivity to bending at different temperatures.

It has also been proposed to attach sensors to various members of a vehicle body, to detect and, in some cases, classify impacts between the vehicle and other vehicles or stationary objects. In such systems, one of the important features is to provide safety for the occupants of the vehicle. Classification of impacts enables a decision to be made as to whether a safety device such as an airbag should be deployed.

Summary of the Invention

The present invention is concerned with detecting and classifying impacts which are likely to be less strong and, frequently, may not result in any great danger to the occupants. An object of the present invention is to detect an impact between a pedestrian and a vehicle and actuate a safety device which will reduce possible injury to the pedestrian, while preventing actuation when impacts with other objects such as poles, barriers, and walls are detected.

Thus according to the present invention, apparatus for sensing impacts between a vehicle and an object, comprises an optical fiber sensor for positioning on the vehicle, the sensor including at least one optical fiber having a light source at one end and a light detector at the other end. The fiber has at least one sensing zone having a light loss area located on the fiber periphery on a side of the fiber facing toward the direction of an expected impact and another light loss area facing away from the direction of expected impact.

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In one aspect of the present invention, an optical fiber array extends across and is attached to a bumper of a vehicle. The array can comprise at least one fiber. One or more sensor zones are provided on each fiber of the array, so that location as well as type of impact may be sensed because the locations of the zones will be

5   known, and zones will be designed to sense a wide range of impact shapes and types, without missing important characteristics used in classification.

The form and arrangement of the sensor or sensors can vary considerably. Sensor zones may be formed according to prior art described in Danisch, L. A., Fiber optic bending and position sensor including a light emission surface formed on

10   a portion of a light guide, U.S. Patent 5,321,257, June 14, 1994; Danisch, L. A., Fiber optic bending and position sensor with selected curved light emission surfaces, U.S. Patent 5,633,494, May 27, 1997, Danisch, L. A., Fiber optic bending and position sensor, European Patent No. EP 0 702 780, October 22, 1997, Danisch, L. A., Topological and motion measuring tool, U.S. Patent 6,127,672, October 3, 2000,

15   Danisch, L. A., Danisch, J. F., and Lutes, J. P., Topological and motion measuring tool (II), U.S. Patent 6,563,107, and Danisch, L. A., Transversely coupled fiber optic sensor for measuring and classifying contact and shape, Canadian Patent Application filed May 11, 1999.

In the above prior art, the sensors are designed with loss on one side,

20   providing an asymmetrical loss and bipolar response, so that a sensor zone will respond with an increase in light throughput to a given polarity of bend, and have a decreased throughput for the opposite polarity of bend. The sensor zone on the fiber has a bipolar response, and each portion within the zone also has the bipolar response. Consequently, the overall response of the zone is the integral of curvature

25   over the zone length, which amounts to the net angle from beginning to end of the zone. This is useful in maintaining angular accuracy for sensors that have curvature detail within a zone, but has the unfortunate consequence that inflected bends (bends containing positive and negative components) within the zone may sum to zero.

30   Impacts with vehicle fronts or sides usually result in 'intrusions' rather than simple bends. The distinction is that intrusions generally include positive and negative bends, so they can be called 'inflected'. The intrusions from small objects

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like a pole or leg are often small in extent (1-6 cm) compared to the length of a bumper (1-2 meters).

Thus it is desirable to include sensor zones within an array that have a robust response to inflected bends (non-bipolar response) within individual sensing zones,
5   yet maintain a significant light throughput when not impacted. Danisch '257 and '494 include descriptions of a fiber that is lossy throughout its circumference and has such a non-bipolar response. However, the circumferential treatment does not meet the requirement for bumper sensing that the throughput be maintained over long sensor lengths or many short consecutive sensor lengths on the same fiber. It is
10   thus a further object of this invention to provide a sensor that has non-bipolar response with high modulation from bending, and also has maximum throughput.

U.S. Patent '494 describes sensors with loss surfaces that are arranged peripherally or axially. Because the impacted shape of a bumper is mainly within the horizontal plane, it is desirable to produce maximum modulation for impacts by
15   providing light loss surfaces within that plane, and to minimize light loss within other planes intersecting the axis of the fiber. By making the light loss surfaces symmetrical (i.e. one faces the impact, the other faces away), a completely non-bipolar response is obtained for impacts. If the surfaces have minimal peripheral extent, then light throughput is maintained.

20   In applications requiring response to more than one plane intersecting the axis of the fiber, more thin light loss strips may be added around the circumference of the fiber. Alternatively, a light loss strip may wind around the fiber in a helical shape. Impacted shapes also typically involve impacted pressure fields that occur at similar locations to the impact bends. It is possible to either ignore the pressure by
25   designing the attachment of the sensors to exclude pressure effects but respond only to shape (such as by mounting the sensor in a slot within the bumper with free air on one side of the sensor), or to use pressure as the means of classifying shapes and measuring the time progression and mass of intrusion, with or without the combined measurement of bending. In this case the light loss areas may be created
30   by using the pressure of an impact to press a film with varying surface profile into the fiber at a known location at the time of impact. Suitable films include woven screens, sandpaper, and sinuated or waffle-patterned plastic. The impression film

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will create microbends in the fiber, which will result in light being lost from the core into the cladding or out of the cladding. Microbends are any series of small bends or sinuations along the length of an intended sensor location. The impression film may be located on the sides of the fiber facing away from and toward the impact, or on

5   one side only. If located on both sides, the effects of light loss due to pressure and of bending while losing light will be synergistic, and symmetrical to both directions of curvature, so it is preferable to have the impression film on both sides. If the impression film is located on one side only, the effects are synergistic for pressure and bend but will be less symmetrical for both directions of bend. Creation of loss

10   surfaces by this method has the advantage that when the sensor is not being impacted, there is very little light loss, so that the change upon impact is very large.

Whether the microbends are applied from both sides or one side of the fiber, the method differs from classical microbend sensing, wherein a fiber is compressed between two flat but waffled platens. In the method of this patent, the platens are

15   flexible so that the fiber receives pressure and microbends, but is free also to flex, so that flexure produces additional light loss due to increased interaction of light with the microbend-induced loss surfaces. A typical configuration for such a sensor is sandwiched between two layers of flexible foam or gel, which will transmit pressure fields but allow flexure. For this reason, included are microbend-inducing patterned

20   films as a means of producing light loss surfaces throughout this patent filing. In the case of arrays of sensors, the impression film may comprise a single film covering the entire array, with patterned areas on the film being placed at desired sensor locations (see Figure 30).

A sensor meeting the objectives can comprise a single fiber having two loss

25   surfaces in opposition extending along the length of the fiber, with a light source connected to one end and a light detector connected to the other end. While effective in indicating an impact, such a sensor cannot give any data as to the position of the impact along the bumper. Another similar arrangement is a single fiber extending in a loop for positioning of light source and light detector at the same

30   end. Both legs of the loop can have a sensor or sensors, or only one length.

For more detailed information concerning the impact, a plurality of sensors can be positioned along a fiber. Alternatively a plurality of fibers can be provided,

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side-by-side, each fiber having a sensor, the sensors spaced along the bumper. A further alternative is a plurality of fibers extending side-by-side, with a plurality of sensors spaced along each fiber. In yet a further arrangement, a sensor can comprise a plurality of light loss surfaces with varying pattern arrangements. Typical arrangements are surfaces spaced axially relative to each other, or spaced peripherally, or a combination of both. The surfaces can extend axially, peripherally or a combination, such as in a helix.

By suitably arranging the sensors across a bumper, it is possible to identify the position of the impact. The sizes and arrangement of light loss surfaces can provide data concerning the impact.

The array of fibers may include bipolar and non-bipolar sensors, so that inflected shapes (e.g. dents) and non-inflected shapes (e.g. shallow curves of one polarity) may be differentiated.

The array of fibers may also include bipolar and non-bipolar sensors which have varying amounts of light loss on one or both sides when straight, thereby imparting a region of operation over which the sensors have a given change in output per bend (slope), and regions over which the sensors have a different slope. The change in slope for a given sensor may occur at different absolute values of bend for positive and negative bend. Thus, these sensors have a region of absolute values of bend over which their response is linear, and two other ranges over which their responses are nonlinear.

The sensor or sensor system of the present invention will normally be utilized with an electronic control system; such control systems are well known in the art for use for various purposes (e.g. seatbelts, air bags, alarms, engine control, etc.). Generally speaking, such an electronic control system will employ an algorithm which will choose which sensor or sensors are most affected by an impact; the control system will also generally store a defined number (e.g. a few hundred) samples of the signal from the most affected sensor(s) in order to process the data obtained over a defined time period, and obtain a "calculation window". The latter time period is relatively short compared to the time necessary to make a deployment

decision.

Further, the algorithm may typically average several samples of early data
and several samples of later data (avg 1, avg 2) and provide a calculation of the
slope of avg 2 versus avg 1 (avg 2 - avg 1 divided by time between them) which will
5   yield a "rate" calculated for two groups of data separated by a gap. The electronic
control system through the algorithm can also compute slopes for all groups of avg 1
and avg 2 samples of earliest data and samples of later data within a calculation
window - in such an arrangement, avg1 and avg2 are separated by an equivalent
amount of time (thus providing a "moving gap rate"). The slopes will be normalized
10   according to measured speed of a vehicle as determined from other sensors (e.g. an
ABS system). The information provided from such a system will generate a
magnitude of slope which will indicate whether a pedestrian impact or some other
type of impact (such as a pole) has occurred. The time when the slope begins to
decrease markedly will indicate the peak time of an impact signal, which would form
15   a classification index. Thus, the magnitude of the slope once the type of object is
determined, together with speed information from e.g. the ABS system, will be used
to determine a mass of the object and rate of intrusion into the bumper. This may be
achieved by utilizing stored information which characterizes the system with test
objects of known masses and various impact velocities which will determine
20   calibration factors.

It is possible for algorithms such as the above to classify impacts measured
by bipolar sensors or non-bipolar sensors. For instance, the bipolar sensors may be
sufficiently numerous to resolve in part the shape of inflected curves. Or, bipolar or
non-bipolar sensors may be used on the basis of locational information only being
25   obtained from the array of sensors, while classification is achieved by calibrating the
signal progression through time against the type of impact (e.g. type of object, mass,
and rate of intrusion). It can be helpful in developing a classification algorithm to
use mechanical, optical, and electronic models of the front end of the car, the
bumper, the optical array on a substrate in the bumper, the optical fibers, the
30   adhesive systems, and the signal processing, combined with extensive
characterization by crash testing to validate the models, in order to get the most
information and best classification from any given type of sensor.

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Further, the front end construction may be changed to diminish bends of multiple polarities within a sensing zone. For instance, stiffness may be increased to prevent inflected bends from occurring on a scale where a single sensor would be subjected to both positive and negative bends. Or, a layer of resilient material like

5   foam may be placed between a stiff front bumper and the sensory fibers. This will have the effect of absorbing inflected bends from the earliest portion of the impact when the contact area between an object and the bumper is small compared to a sensor length, and thereafter (after a short delay) transmitting all of the non-inflected bend.

10   For any type or configuration of sensor and front end construction, the classification accuracy may be optimized by using combinations of algorithms, testing, and modelling approaches. This invention is aimed at optimizing the . locational and time-progression aspects of the signal contents, and minimizing the number of sensors required to make a classification.

15   The invention is concerned with the method of detecting, and where required, classifying impacts with a vehicle, and also an apparatus for such detection, and classification. Apparatus, in accordance with the invention, can comprise an optical fiber array, comprising one or more fibers, with one or more sensors, as an entity for attachment to a bumper. Light sources and detectors can be previously attached for

20   the apparatus to be ready for applying and connection to the control unit - usually positioned within the vehicle. Alternatively, the light sources and detectors can be connected to the fiber array after the fiber array has been applied to the bumper.

A method, in accordance with the invention, comprises applying an optical fiber array to a bumper of a vehicle, the optical fiber array having one or more

25   sensors extending along the array, each sensor having light loss surfaces in opposition, detecting a variation in a light signal in the fiber array indication of an impact with and deformation of the bumper, producing an output signal related to the variation in light signal, and using the output to control actuation of a safety device.

In other cases also in accord with the invention, the light loss surface within a

30   sensor length is arranged to symmetrically include each plane of application that is of interest. By "symmetrically include" it is meant that the light loss surface occurs in the periphery of the fiber on the portion of the periphery facing an impact, and on the

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portion facing away from the impact. Furthermore, the width of the light loss surface is adjusted to be narrow enough to maximize throughput for an unbent fiber, and wide enough or containing sufficient loss regions within a given width and length to produce an acceptably large modulation of light level with bending.

5   Light loss zones may preferably be created by abrasion, ablation, or impact, combined with light-absorption. The objective is to create a loss zone with an amount of loss invariant over time, but that varies with bending. Treatment to form the loss zone may vary from low-depth abrasion of the surface, in which case a thoroughly absorptive layer is applied to ensure full loss of scattered light, to high-

10   depth notches, which may not require significant additional absorptive layer to obtain full modulation by bend. However, the light-absorbing layer will always be desirable for reducing the effects of light from other sources external to the fiber, and may include adhesive properties and sealing properties. An example of abrasion is roughening by sandpaper or sand-blasting. An example of ablation is removal of

15   material at low temperature by ultraviolet laser. An example of impact treatment is pressing a sharpened blade into the fiber to create notches.

        In the description of various embodiments of the invention above, and in the detailed description below the term "optical sensor" or "optical fiber sensor" or "optical fiber array" includes fiber or light guides of any cross sectional shape and

20   size.

Brief Description of the Drawings

Figure 1 is a perspective view of the front portion of a vehicle embodying the invention;

25   Figures 2(a) and 2(b) illustrate sensor deformations;

        Figures 3, 4 and 5 illustrate various characteristic curves for sensors;

        Figures 6 and 7 are end view and side view respectively of non-distributed sensing zone;

        Figures 8 and 9 are similar views at a sensing zone having axially and

30   peripherally distributed loss regions;

        Figures 10 and 11 are side views of further arrangements of loss regions;

        Figures 12, 13 and 14 are an end view, side view and perspective view

respectively of a sensor having two peripherally distributed axial loss regions.

Figures 15 and 16 are side views illustrating two different forms of surface treatment at loss regions;

Figures 17, 18 and 19 are side views, similar to Figure 9, illustrating other arrangements of loss regions on a sensor;

Figure 20, a side view as in Figures 17, 18 and 19, illustrates an alternative form or shape of loss region;

Figures 21, 22 and 23 are end view, side view and perspective view respectively of a fiber having a sensor with four peripherally distributed axially extending light loss regions;

Figures 24, 25 and 26 illustrate different forms of an array;

Figures 27, 28 and 29 illustrate further different forms of array;

Figure 30 is a side view of a sensing zone, incorporating an impression film on the fiber;

Figure 31 is a cross-section through a typical bumper, with array applied; and,

Figure 32 is the section in the circle A on Figure 30 to a larger scale.

Detailed Description of the Preferred Embodiment

Figure 1 illustrates the front end 10 of a vehicle having a bumper 12 extending across at the front. Attached to the bumper 12 is an optical fiber sensor array 14. In the particular arrangement shown, a light emitting source 16 and a light detector 18 are connected to the fiber or fibers in the array 14, one at each end. As described later light source 16 and light detector 18 can both be at the same end. The light source and light detector are connected to a control system (not shown) in the vehicle. Devices 20 are provided to "pop" or lift the hood 22, on receipt of a signal from the control system.

The invention provides various forms of optical fiber arrays and various forms of sensors for detecting, classifying and measuring inflected and non-inflected bends, their progression in time and to calculate shape, mass and velocity of intruding objects and also to identify such objects by shape, resilience, vibration and dampening. It is not necessarily a requirement that all of these determinations be obtained at all times, the actual determination being selected to suit the particular

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requirements of the method and apparatus.

Figure 2(a) illustrates a sensor zone or area, indicated generally at 30, comprising a fiber 32 having a light loss area 34, on one side. A deformation 36 is shown. This is a bipolar situation, with the loss area on one side, and the bends 38

5   and 40 may add to zero or another deceptive value. This cannot be repaired by subsequently taking the absolute value of the modulated signal. The ability to sense inflected shapes can be improved somewhat if the single loss area is arranged to produce a bipolar but nonlinear response (more modulation for one polarity of bend than another, yet still bipolar). In that case, inflected bends with equal positive and

10   negative components will produce a non-zero change in throughput, but bends with unequal components can still produce no response or a misleading response (e.g. two different 'dents' can produce the same response).

Figure 2(b) illustrates a non-bipolar arrangement, with the fiber 32 having light loss areas 34 and 42 on opposite sides of the fiber. The modulation of the light

15   signal through the fiber will be the sum of the absolute values of the bends, so there will always be a non-zero result. It might be thought that with the loss areas on opposite sides, a given bend would lead to increased throughput due to the concave-out side and decreased throughput for the other side, and a cancellation of modulation would occur. However, this is not the case because most of the light in

20   the fiber is directed toward the convex-out side and impinges on the loss area, and the other side has minimal interaction with the light.

Various characteristic curves for sensors can be combined in an array to facilitate classification and measurement.

Figures 3, 4 and 5 illustrate different curves which can be obtained. Figure 3

25   is for a fiber having light loss area on both sides, with a bi-polar and symmetrically linear characteristic. In Figure 4 there is a light loss area on one side but small loss or unequal loss areas on both sides. This gives a bipolar and asymmetrical linear (non-linear) characteristic. In Figure 5 there is a light loss area on one side optimized for linearity. This gives a bipolar and symmetrically linear characteristic.

30   The configuration of Figure 4 with two unequally lossy areas on opposite sides may take on the characteristic curve shown in Figure 4, in which case the response is bipolar and linear for positive and negative bends but the response is

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attenuated at a different absolute value of positive bend than of negative bend, depending on the amount of loss per unit bend for each side. As shown in Figure 4, for small bends, the response is linear. For larger absolute values of bend, the slope of the response curve is attenuated as shown in Figure 4, imparting a nonlinear

5   property to the sensor, with a different breakpoint of slope (change from large slope to lesser slope) for positive and negative bends. The loss areas may be adjusted in width, depth, or number of loss sites per surface area of loss zone to take on different values of loss. By varying these parameters, the response may be tailored to have the characteristic curve shown or, if there is very little or no loss on one side,

10 the characteristic curve within a range of bend intensities comprising all intensities of practical use, may be the same as that of a fiber with a loss zone on one side only. The cases illustrated in Figures 3, 4 and 5 demonstrate a continuum of responses that may be produced by various cases of bilateral loss (loss areas on both sides), varying from equal loss on both sides to no loss on one side. All of these cases are

15 preferable to circularly symmetrical loss (loss area completely surrounding the circumference) because the geometry is made specific to a plane of maximum response, and the throughput is thereby maximized for a given amount of response to bend.

The design of a sensor of any given characteristic curve involves tradeoffs of

20 modulation percentage and throughput. In Figures 6 and 7, the fiber 32 has a complete peripheral loss area 34, extending axially. This acts as a large single loss area to detect a bend in any plane but has a low throughput for a given modulation percentage.

In Figures 8 and 9 a sensing zone or area has a plurality of loss areas 34,

25 distributed peripherally and axially, again detecting a bend in any plane. This gives an increased throughput with little loss in modulation percentage if an impact is aligned in a plane containing the light loss areas. This has improved throughput.

In Figure 10 there are axially and peripherally distributed light loss areas optimized to detect a bend in a single plane - the plane of drawing.

30 Figure 11 is similar to Figure 10, but optimized for throughput. By displacing the loss areas axially on one side of the fiber vs. the other, the throughput can be enhanced because modes lost on one side of a straight fiber, if not lost, but rather

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reflected, would have formed a significant population of the modes striking a downstream loss area on the other side of the fiber. When the fiber is bent during an impact, this situation changes, so that modulation is similar to that achieved without axial displacement of loss areas on one side. Axial displacement is limited
5   usually to approximately one half to one length of a loss area, and should in any event not be so large that the loss area on one side of the fiber is exposed to significantly different shapes than that on the other side.

For sensors covering from millimeters up to a few centimeters, the loss areas can be continuous along the fiber, and have large features resulting in large loss
10   within the loss area, but throughput is kept high by limiting the peripheral extent to the plane of maximum sensitivity (i.e., narrow, continuous loss areas facing toward and away from an impact). Treatment of the fiber surface can be carried out, as by impression, laser ablation, abrasion and other means. Figures 12, 13 and 14 illustrate a fiber 32 having two peripherally spaced axially extending loss areas.
15   These form a sensing zone, or region, maximally sensitive in the plane containing the loss areas. Figures 15 and 16 illustrate two alternative forms of surface treatment - Figure 15 is serrated and Figure 16 crenellated. The serrations and crenellations penetrate the cladding and can also penetrate the core.

In general, the sensor zones or regions are comprised of continuous or
20   distributed light loss areas which can be spaced peripherally and axially. Preferably, the peripheral distribution, or spacing, should be limited to that required to achieve a characteristic curve (such as non-bipolar and linear) with maximum sensitivity in the plane of impact (i.e., treat two sides), and axial distribution, or spacing, should be optimized for a trade-off of throughput and modulation percentage. Figures 7 and 8,
25   above, is one form of light loss areas and Figures 17, 18, 19 and 20 illustrate further various forms of the spacing of light loss regions 34. In Figure 17 the areas 34 are in a helical pattern, with elongate areas 34 extending axially. In Figure 18 the areas 34 are in a helical formation, with the elongate areas 34 extending along the helical line. In Figure 19 the areas 34 are on opposite sides, alternating axially, side-by-side.
30   Figure 20 illustrates areas 34 of a different shape, in the example generally circular. In the example, the areas are spaced helically, axially along the fiber 32.

Figures 21, 22 and 23 illustrate an example of a high-throughput fiber

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sensitive in two planes. The sensor zone 30 of fiber 32 has four peripherally spaced axially extending light loss areas 34. This forms a sensing zone maximally sensitive in two planes.

System design of a sensor array can vary. Figures 24, 25 and 26 illustrate three arrays. In Figure 24, there is a single light guide or fiber 32, with a light source 16 at one end and a light detector 18 at the other. There is a sensor zone or region 30 which has one or more light loss areas, extending axially and peripherally spaced to fall symmetrically in a plane of maximum sensitivity. In Figure 25 there is a multiplicity of light guides or fibers 32, in the example three, with light sources 16 at one end and light detectors 18 at the other. The sensor zones or regions 30 are spaced axially, each at a unique axial location. In Figure 26 there is a plurality of light guides or fibers 32 each having a light source 16, a light detector 18, and a series of sensor zones or regions 30 axially spaced along each fiber. The sensor zones in the fibers are axially spaced so that they are axially distributed relative to the sensor zone in each fiber. In this arrangement wider objects actuate more sensors. Alternatively mass and velocity (and type) are inferred from the time progression of the signals, but the location of the impact will not be known.

Where peripherally opposed pairs of light loss bands or areas are formed, the bands or areas of a pair are preferably peripherally aligned. However, one band or area of a pair can be axially displaced relative to the other less than half the band length on the axial centres of the bands.

The optical fiber sensor array (14 in Figure 1) can be made in a continuous strip, cut to length. It can have the light source and detector at both ends or at one end.

Figures 27, 28 and 29 illustrate arrangements in which the optical fibers in the array are looped back on themselves, providing for the light source and the light detector to be at the same end. In Figure 27 the fibers 32 are looped and the sensors 30 are positioned to provide an axially spaced positioning. In Figure 28 the light sources, light detectors and electronics for the control system are located at a single location 40. A ribbon cable of optical fibers can be manufactured in a continuous band, with the sensor zones formed, and the ribbon cut to length, then looped for return. The sensors can be in either half of the ribbon if both halves of the

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ribbon face the impact.

In Figure 29, a fiber ribbon is looped to run at various heights to form an array for detecting both axial and lateral locations and shapes of impacts. Sensors are positioned as required.

5   In Figures 24, 25 and 26 and in Figures 27, 28 and 29, the direction of impact is into the plane of the drawing.

Figure 30 illustrates a sensor zone 30 on a fiber 32, having an impression film on both sides, the films having a textured pattern 42 for impression of microbends in a fiber when pressure is present. Light loss occurs from pressure and bending in

10   presence of the light loss area created by the microbends (synergistic effect). This is discussed above.

The optical fiber array 14 is attached to the bumper 12, for example the front outside surface as illustrated in Figures 30 and 31. Figure 31 shows the array to a larger scale and, again, as an example, three optical fibers 32 are shown.

15   Alternatively, the array 14 can be attached on the inside surface of the bumper, as indicated in dotted outline 14(a) in Figure 31.

The array can be applied to the bumper at a completion stage of the bumper, for example, or applied after complete manufacture. It is possible to apply the array after final assembly of the vehicle. Such after assembly attachment would occur, for

20   example, as a retroactive up-date to existing vehicles. In such instances an array could be packaged and sold as an item for attachment to existing vehicles. Suitable electronic connections would be made to a control system, or the like, positioned at a convenient place in the vehicle.

In operation, normally the sensor(s) on the bumper will convert light signals to

25   digital signals, which will be fed to an electronic control system having an algorithm such as that described above (other algorithms can be used as will be understood by those skilled in the art). Once the signals are received by the electronic control system, the system will send a trigger to the safety deployment system (such as the activation of the hood being raised, etc.) when required.

30   The array installation can vary in complexity depending upon the desired information required. Thus it can merely detect, and indicate, that an impact occurred. Towards the other extreme, the speed of distortion or bending of the

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bumper and array, the severity, possibly the shape, and also the position can be detected, with appropriate signals produced. The signals can be used to cause actuation of various safety devices. In addition, or alternative to the popping open of a hood, actuation of air bags can be obtained. A further possibility is the actuation of

5   a safety device, which could be the opening of the hood, to act as a deflector, such as would act to deflect an animal either up, or to the side, on impact, or to activate the airbags to protect occupants when an animal strike is detected. It often occurs that when a vehicle hits an animal, such as a horse, deer or other similar animal, the animal often goes through the windshield, causing severe injuries to occupants of

10   the vehicle.

Some objectives for installations are:

(a)   a low sensor "count" for example sixteen or fewer, for economical reasons;

(b)   classification by type of impact and measurement of mass and velocity,

15   which can be of more importance than exact knowledge of location (a likely goal being to locate to nearest quarter of a bumper length);

(c)   response from a sensor should include information that can be processed to extract mass and velocity information - should be more than an on/off information; and,

20   (d)   response should be the same anywhere along a given sensitized length of fiber (sensor length).

A most useful type of sensor is in most cases a linear bipolar one, but non linear and non-bipolar sensors can also be used if suitably designed and installed, in

25   cases where economy dictates the use of fewer sensors.

Broadly, a sensor zone on a fiber provides a sensor having a variety of forms of light loss areas. The areas can vary from those which extend completely peripherally around the fiber, to thin strips along the fiber. With peripherally extending loss areas, two or more are spaced axially, to give an axial dimension to

30   the sensor. For thin strips, normally two at least are provided, spaced circumferentially, and extending axially to give an axial dimension. Other forms, such as helical and other formations can be provided, and the actual shape of the light

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loss areas can vary, subject only to the requirement that a sensor has light loss areas spaced peripherally and extending axially.

CLAIMS:

1.   An apparatus for sensing impacts between a vehicle and an object, comprising: an optical fiber sensor for positioning on the vehicle, said optical fiber sensor including at least one optical fiber, a light source at one end of said optical fiber, a light detector at the other end of said optical fiber, and at least one sensing zone on the fiber, each said sensing zone comprising a light loss area located on the periphery of the fiber, on a side of the fiber facing towards a direction of expected impact and on another side of the fiber facing away from the direction of the expected impact.

2.   The apparatus as claimed in claim 1, said optical fiber sensor comprising an optical fiber array for positioning on a front bumper of a vehicle.

3.   The apparatus as claimed in claim 1, said sensing zone comprising a single helical band of light loss areas. :

4.   The apparatus as claimed in claim 1, said sensing zone comprising a band of light loss area facing toward the direction of expected impact and another band of light loss area facing away from the direction of expected impact.

5.   The apparatus as claimed in claim 1, said sensing zone comprising pairs of light loss area bands, each pair including a band facing the expected direction of impact and another band facing away from the expected direction of impact.

6.   The apparatus as claimed in claim 4 or 5, wherein at least one band is treated by abrasion and light-absorptive coating.

7.   The apparatus as claimed in claim 4 or 5, wherein at least one band is treated by laser ablation and light-absorptive coating.

8.   The apparatus as claimed in claim 4 or 5, wherein at least one band is treated

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by impact abrasion and light-absorptive coating.

9.   The apparatus as claimed in claim 4 or 5, wherein at least one band is treated
         by impact with a sharp tool and light-absorptive coating.

10.   The apparatus as claimed in any one of claims 4 to 9, wherein said optical
         fiber is adapted to be positioned in a mechanical structure which prevents the
         formation of bends having multiple polarities within the length of said sensing
         zone.

11.   The apparatus as claimed in any one of claims 4 to 10, wherein said
         mechanical structure is a bumper including resilient foam interspersed
         between the front face of said bumper and said optical fiber.

12.   The apparatus as claimed in claim 5, the axial centres of said bands of said
         pair being axially aligned.

13.   The apparatus as claimed in claim 5, the axial centre of one of said bands of
         a pair axially displaced from the axial centre of the other one of said pair up to
         half the axial separation between centers of said pairs.

14.   The apparatus as claimed in claim 1, comprising a plurality of said optical
         fibers extending in a narrow lateral band, for simultaneous exposure to
         impact, said sensing zones positioned at different axial locations on each
         fiber.

15.   Apparatus as claimed in claim 14, said axial locations distinct and non-
         repeating over each fiber for locational information indicative of impact, and
         intrusion depth, shape and time progression.

16.   Apparatus as claimed in claim 14, said axial locations on each fiber repeated
         at regular intervals along each fiber, the axial locations on each fiber differing

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from the axial locations on the other fibers, the entire axial extent being
sensitive to impacts but non-indicative of the axial location of an impact.

17.   Apparatus as claimed in claim 5, including at least one fiber having non-
       bipolar response and at least one fiber with bipolar response for
       differentiation between inflected intrusions and non-inflected intrusions.

18.   Apparatus as claimed in claim 1, comprising a plurality of said sensing zones
       on a fiber.

19.   Apparatus as claimed in claim 1, said sensing zone comprising peripherally
       extending light loss areas, spaced axially.

20.   Apparatus as claimed in claim 1, said sensor zone comprising a plurality of
       bands of light loss area extending laterally, said bands spaced peripherally.

21.   Apparatus as claimed in claim 1, said sensor zone comprising a plurality of
       strips spaced axially, the longitudinal axes of said strips extending axially, said
       strips extending in a helix.

22.   Apparatus as claimed in claim 1, said sensor zones comprising a plurality of
       strips spaced axially, the strips extending in a helix, the longitudinal axes of
       the strips extending in said helix.

23.   Apparatus as claimed in claim 1, including surface treatment of said fiber at
       said light loss area.

24.   Apparatus as claimed in claim 1, including an impression film on each side of
       the fiber, at said sensing zone, each film having a textured relief pattern.

25.   Apparatus as claimed in claim 1, said light loss area non-rectangular.

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26.   Apparatus as claimed in claim 1, said fiber shaped to form a loop with said ends adjacent.

27.   Apparatus as claimed in claim 1, said fiber shaped to extend in a series of loops.

28.   Apparatus as claimed in claim 26, said fiber comprising a ribbon cable, said ends connected to a unitary device comprising a light source, a light detector and associated electronic circuitry.

29.   A bumper for a vehicle including an impact sensing apparatus as claimed in claim 1.

30.   Apparatus for sensing impact between a vehicle front bumper and an object, comprising:
        an array of optical fibers attached to a front surface of the bumper, each fiber having a plurality of sensing zones comprising narrow axial light loss strips facing toward and away from the direction of impact with the front bumper, the signal response of each fiber being the sum of bending of the light loss strips, independent of polarity.

31.   Apparatus for sensing impacts between a vehicle and an object, comprising:
        an optical fiber sensor for positioning on the vehicle, said optical fiber sensor including at least one optical fiber, a light source at one end of said optical fiber, a light detector at the other end of said optical fiber, and at least one sensing zone on the fiber, each said sensing zone comprising a light loss area located on the periphery of the fiber, on a first side of the fiber facing towards a direction of expected impact and on a second side of the fiber facing away from the direction of the expected impact, the amount of light loss at said first side being adjusted relative to the amount of light loss at said second side to obtain a desired response to bends of at least one polarity within said sensing zone.

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32. The apparatus as claimed in claim 31, wherein said light loss of said first side is adjusted to produce a bipolar response in which the polarity of curvature within each said sensing zone is indicated by the polarity of light modulation where the number of sensors per length of array need not be minimized and data from time progression of the impact are insufficient to classify impacts as to type of object and mass.

33. The apparatus as claimed in claim 32, wherein one of said loss areas has minimal or zero loss.

34. The apparatus as claimed in claim 31, wherein said light loss of said first side is adjusted to produce a non-bipolar response in which the polarity of curvature within each said sensor zone is not indicated by polarity of light modulation where the number of sensors per length of array is to be minimized and data from time progression of the impact is sufficient to classify impacts as to type of object and mass.

35. The apparatus as claimed in any one of claims 31 to 34, wherein said light loss of said first side is adjusted to produce an attenuated response to bending above a first desired positive bend value and an attenuated response to bending below a second desired negative bend value.

36. The apparatus as claimed in any one of claims 31 to 35, wherein said sensing zone further comprises at least one band treated by abrasion and light-absorptive coating.

37. The apparatus as claimed in any one of claims 31 to 35, wherein said sensing zone further comprises at least one band treated by laser ablation and light-absorptive coating.

38. The apparatus as claimed in any one of claims 31 to 35, wherein said sensing

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zone further comprises at least one band treated by impact abrasion and light-absorptive coating.

39.   The apparatus as claimed in any one of claims 31 to 35, wherein said sensing zone further comprises at least one band treated by impact with a sharp tool and light-absorptive coating.

40.   The apparatus as claimed in any one of claims 31 to 35, wherein said optical fiber is adapted to be positioned in a mechanical structure which prevents the formation of bends having multiple polarities within the length of said sensing zone.

41.   The apparatus as claimed in claim 40, wherein said mechanical structure is a bumper including a resilient foam interspersed between the front face of said bumper and said optical fiber.

42.   In a vehicle having a pedestrian impact sensing system, the improvement wherein said vehicle includes:
        a plurality of sensors mounted in the front area of said vehicle and adapted to sense an impact between a pedestrian and the front area of the vehicle;
        said sensors each comprising a plurality of light loss areas on a fiber, spaced axially; and
        a data processing control unit having stored data, said data processing central control unit being adapted to compare an event upon receipt of a signal from at least one of said sensors with stored data, and being adapted to generate an output signal upon evidence of a threshold value determined by said stored data, said output signal adapted to actuate a safety device.

43.   A method of sensing impact between a vehicle and an object comprising:
        providing said vehicle with a front structure having a plurality of sensors, each sensor comprising a plurality of light loss areas on a fiber, spaced axially, each sensor having signal output means for feeding a signal upon an impact

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to a data processing control unit;

providing a data processing control unit having stored algorithms for measuring and classifying impact shape, mass, and velocity based on the signal outputs from the sensors; said control unit being operatively associated with said signal output means of each of said sensors;

said data processing control unit being adapted to compare an event upon receipt of a signal from at least one sensor, with stored data in said control unit; and,

said control unit being adapted to generate an output signal upon evidence of a threshold value determined by said stored data, said output signal being adapted to actuate a safety device.

44.   A method as claimed in claim 43, comprising positioning an optical fiber array on a front bumper of a vehicle, said optical fiber array comprising at least one optical fiber having a plurality of said sensors, each sensor comprising a light loss area located on the periphery of the fiber on a side facing towards a direction of expected impact and on another side of the fiber facing away from the direction of expected impact.

45.   A method of sensing impact between a vehicle and an object comprising: positioning an optical fiber sensor on a vehicle, said sensor including at least one optical fiber having a light source at one end, a light detector at the other end and at least one sensing zone on the fiber, each sensing zone comprising a light loss area located on the periphery of the fiber, on a side of the fiber facing toward a direction of expected impact and another light loss area located on the periphery of a fiber on a side of the fiber facing away from a direction of expected impact, detecting modulation of a light signal resulting from said impact and generating a signal for actuation of a safety device.

Fig 1

Fig 2(a)

Fig 2(b)

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Light throughput

Fig 3

bend

Light throughput

Fig 4

bend

Light throughput

Fig 5

bend

Fig 6

32   34

Fig 7

30

34

32

Fig 8

34

32

Fig 9

34   30   32

Fig 10

30   32

34

Fig 11

30   32

34
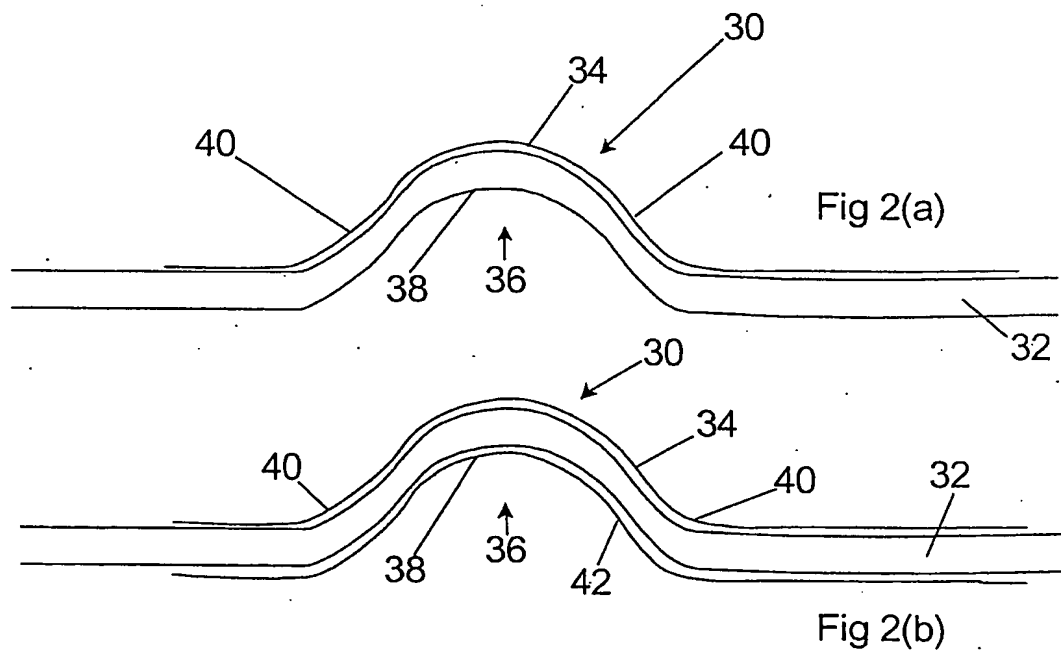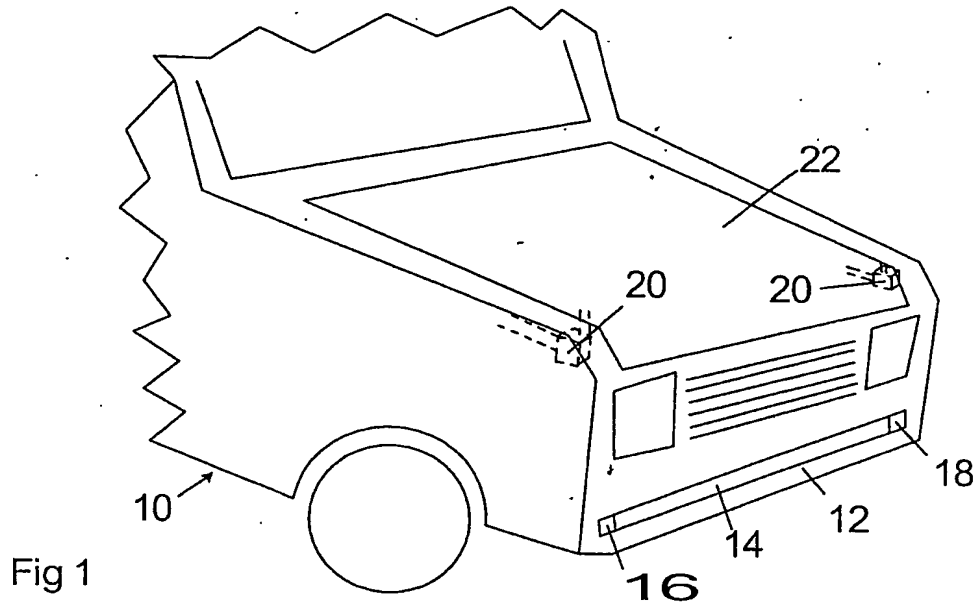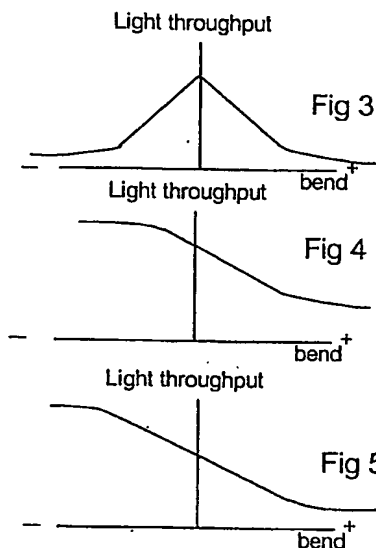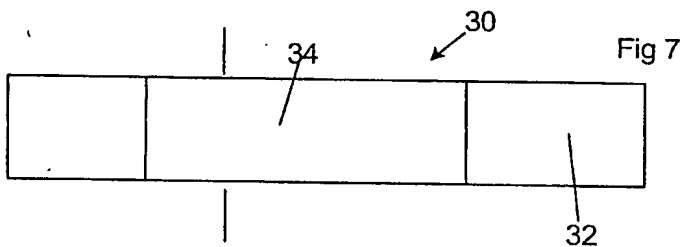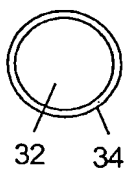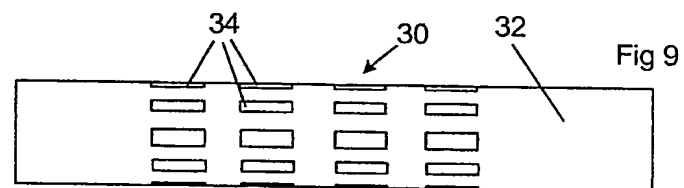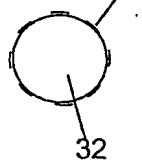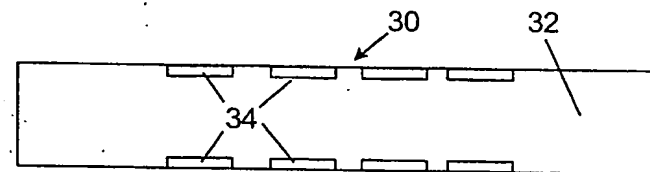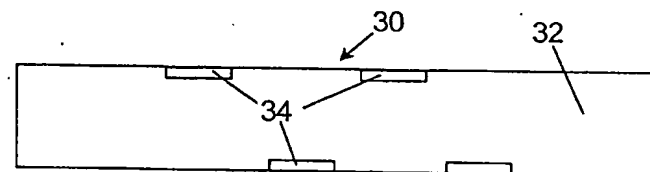
Fig 12

Fig 13

Fig 14

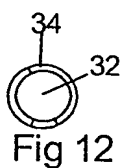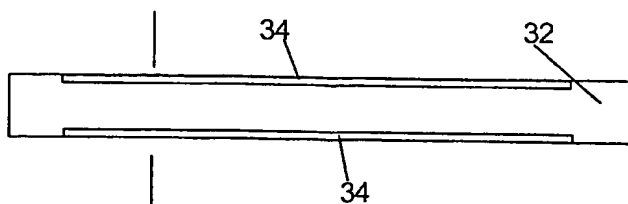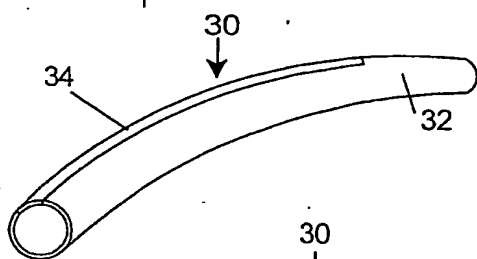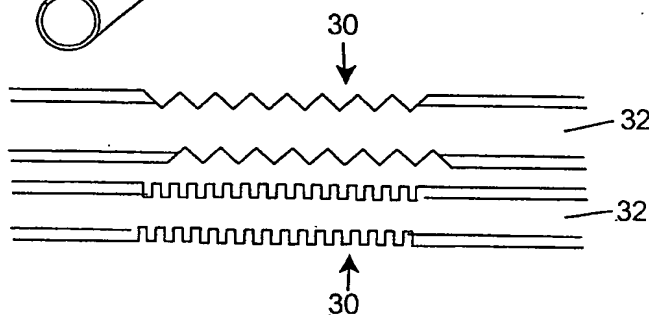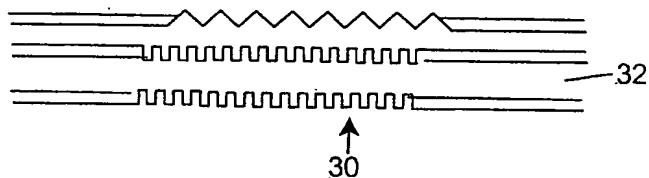Fig 15

Fig 16
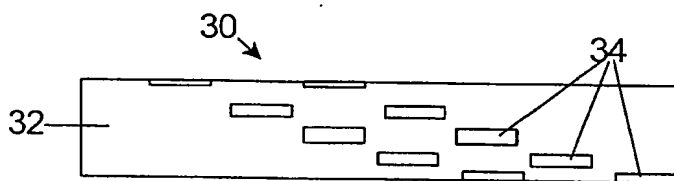
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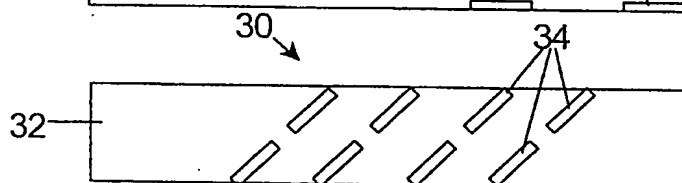
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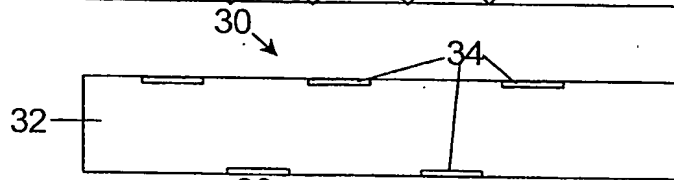
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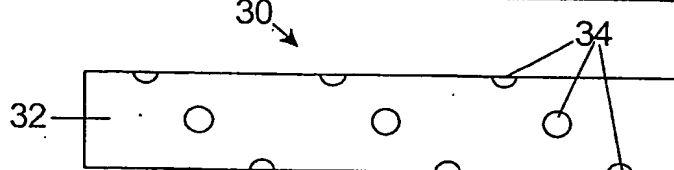
Fig 20
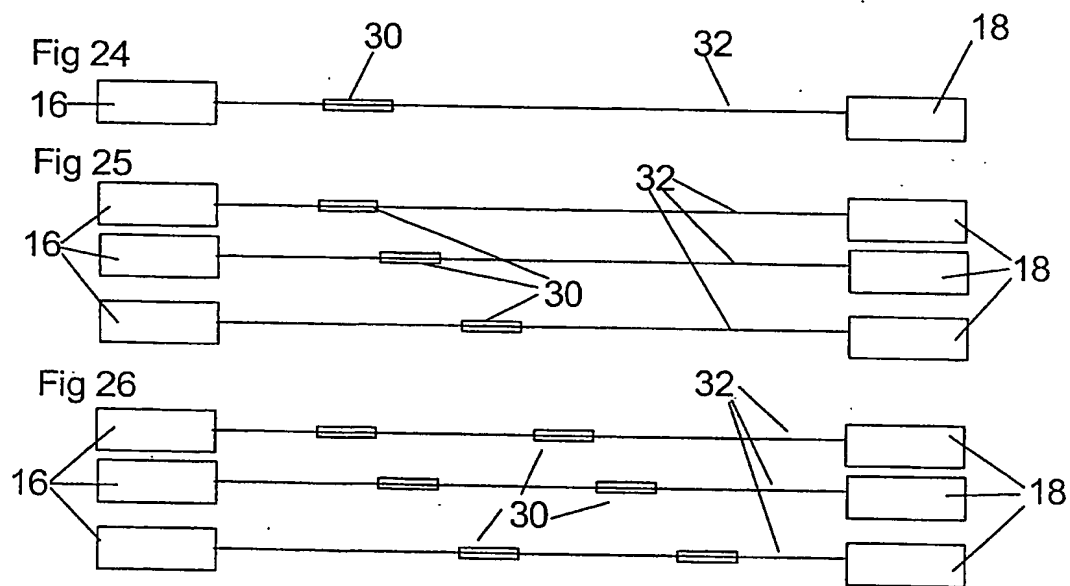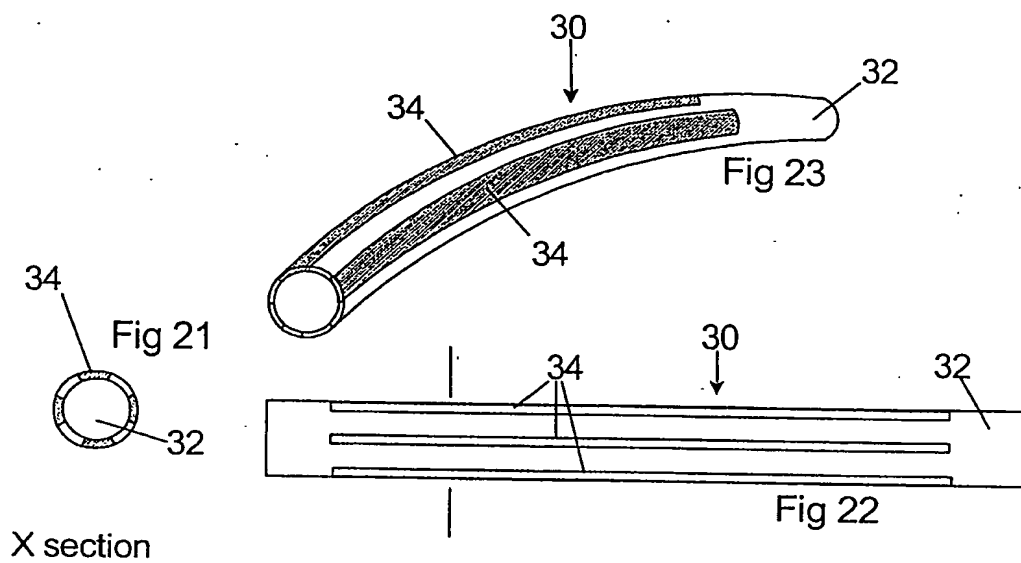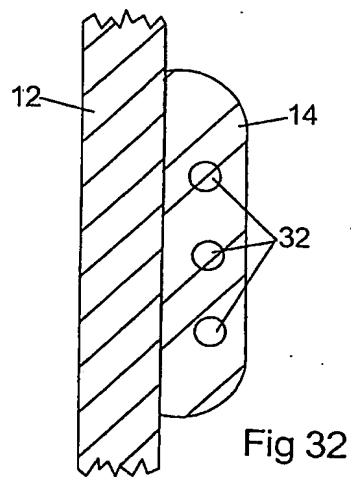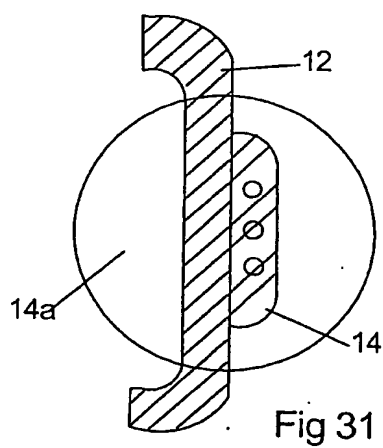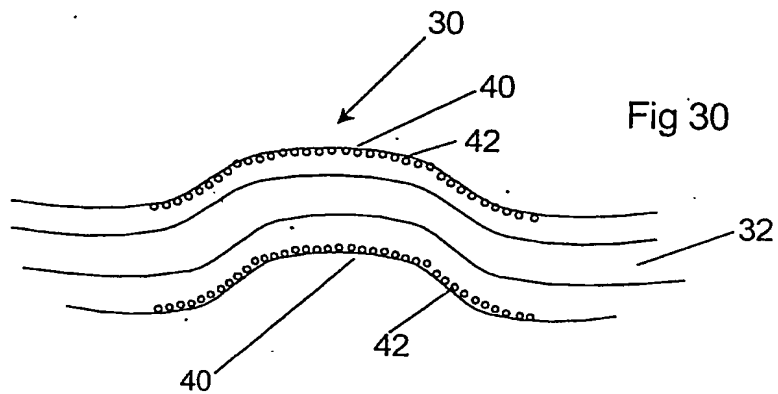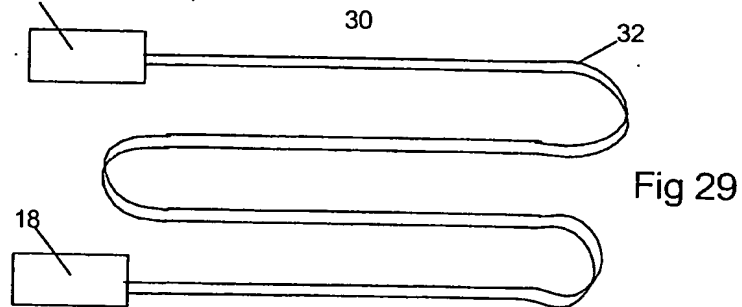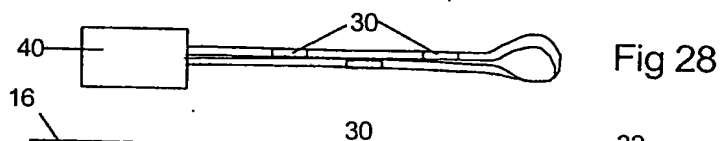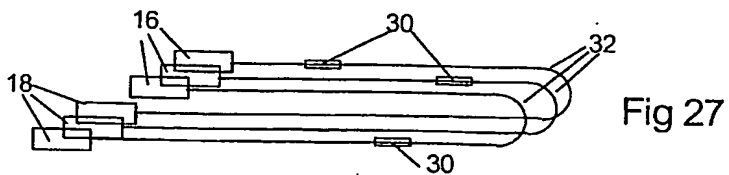
4/5

30

32

34

Fig 23

34

34

Fig 21

32

X section

34

30

32

Fig 22

Fig 24

30   32   18

16

Fig 25

32

16   30   18

Fig 26

32

16   30   18

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Fig 27

Fig 28

Fig 29

Fig 30

Fig 31

Fig 32

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   B60R21/01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   B60R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 00/32449 A (CANPOLAR EAST INC ; BALDWIN LORNA H (CA); REIMER ERNEST M (CA)) 8 June 2000 (2000-06-08) page 5, paragraph 4 - page 9, paragraph 4 page 11, paragraph 3; figure 2 page 14, paragraph 3; figure 9	1,29-31, 42,43,45
A	DE 44 07 763 A (BOSCH GMBH ROBERT) 14 September 1995 (1995-09-14) column 1, line 64 - column 2, line 19 column 4, line 23 - line 47; figures	1,29-31, 42,43,45
A	US 5 633 494 A (DANISCH LEE) 27 May 1997 (1997-05-27) cited in the application column 6, line 52 - column 9, line 9; figures	1,29-31, 42,43,45

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[X] Further documents are listed in the continuation of box C. [X] Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 July 2004	03/08/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Daehnhardt, A

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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 100 31 406 A (DAIMLER CHRYSLER AG) 17 January 2002 (2002-01-17) paragraph '0004! - paragraph '0016!	1,29-31, 42,43,45
A	WO 00/68645 A (DANISCH LEE A) 16 November 2000 (2000-11-16) page 5, paragraph 1 - page 18, paragraph 1; figures	1,29-31, 42,43,45
A	US 6 329 910 B1 (FARRINGTON ANDREW ROY) 11 December 2001 (2001-12-11) cited in the application column 1, line 40 - column 3, line 3; figures	1,29-31, 42,43,45

4

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 0032449	A	08-06-2000	CA	2254538 A1	26-05-2000
			AT	252993 T	15-11-2003
			AU	1369700 A	19-06-2000
			WO	0032449 A1	08-06-2000
			CN	1328511 T	26-12-2001
			DE	69912473 D1	04-12-2003
			DE	69912473 T2	24-06-2004
			EP	1133420 A1	19-09-2001
			JP	2002531812 T	24-09-2002
			US	6607212 B1	19-08-2003
DE 4407763	A	14-09-1995	DE	4407763 A1	14-09-1995
US 5633494	A	27-05-1997	US	5321257 A	14-06-1994
			AT	159586 T	15-11-1997
			AU	6967094 A	03-01-1995
			WO	9429671 A1	22-12-1994
			DE	69406447 D1	27-11-1997
			DE	69406447 T2	14-05-1998
			EP	0702780 A1	27-03-1996
			JP	8511343 T	26-11-1996
			CA	2073162 A1	01-02-1993
DE 10031406	A	17-01-2002	DE	10031406 A1	17-01-2002
WO 0068645	A	16-11-2000	CA	2271918 A1	11-11-2000
			AU	4529700 A	21-11-2000
			WO	0068645 A1	16-11-2000
			CA	2307468 A1	11-11-2000
			EP	1181504 A1	27-02-2002
US 6329910	B1	11-12-2001	GB	2347539 A	06-09-2000